

## New AGNs discovered by H.E.S.S.

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**Y. Becherini<sup>a,b</sup>, B. Behera<sup>c</sup>, J. Biteau<sup>b</sup>, M. Cerruti<sup>d</sup>, B. Giebels<sup>b</sup>, J.-P. Lenain<sup>d</sup>,  
M. de Naurois<sup>b</sup>, M. Punch<sup>a</sup>, M. Raue<sup>e</sup>, D. Sanchez<sup>f</sup>, F. Volpe<sup>f</sup>, A. Zech<sup>d</sup> on behalf of  
the H.E.S.S. Collaboration**

<sup>a</sup>*Astroparticule et Cosmologie (APC), CNRS, Université Paris Diderot – Paris 7, Paris, France*

<sup>b</sup>*Laboratoire Leprince-Ringuet, Ecole Polytechnique, CNRS/IN2P3, Palaiseau, France*

<sup>c</sup>*Landessternwarte, Universitat Heidelberg, Heidelberg, Germany*

<sup>d</sup>*Laboratoire Univers et Theories (LUTH), Observatoire de Paris, CNRS, Université Paris  
Diderot – Paris 7, Meudon, France*

<sup>e</sup>*Universitat Hambourg, Institut für Experimentalphysik, Hambourg, Germany*

<sup>f</sup>*Max-Planck-Institut für Kernphysik, Heidelberg, Germany*

*E-mail: Yvonne.Becherini@apc.univ-paris7.fr*

During the last year, six new Active Galactic Nuclei (AGN) have been discovered and studied by H.E.S.S. at Very High Energies (VHE). Some of these recent discoveries have been made thanks to new enhanced analysis methods and are presented at this conference for the first time. The three blazars 1ES 0414 + 009, SHBL J001355.9 – 185406 and 1RXS J101015.9 – 311909 have been targeted for observation due to their high levels of radio and X-ray fluxes, while the *Fermi*/LAT catalogue of bright sources triggered the observation of PKS 0447 – 439 and AP Librae. Additionally, the BL Lac 1ES 1312 – 423 was discovered in the field-of-view (FoV) of Centaurus A thanks to the large exposure dedicated by H.E.S.S. to this particularly interesting source. The newly-discovered sources are presented here and in three companion presentations at this conference.

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\*Speaker.

## 1. Introduction

Eight years of operation of the High Energy Stereoscopic System (H.E.S.S.) have been at the heart of a breakthrough in the field of  $\gamma$ -ray VHE astronomy: more than 70  $\gamma$ -ray sources have been discovered, 30 of which are extra-galactic. H.E.S.S. will continue operation while awaiting the completion of the ongoing upgrade of the array, which will lead to the phase II of the experiment (see Sec. 8 for more details). Meanwhile, H.E.S.S. is improving its sensitivity also through the development and successful application of new enhanced analysis methods, such as for instance [1] and [2]. These new analysis methods allow the detection of new faint  $\gamma$ -ray sources, having very low flux levels, i.e. of the order of 1% C.U.<sup>1</sup> or less, in a moderate amount of observation time. Six newly-discovered AGNs will be presented here, the detections of two of which (1RXS J101015.9 – 311909 and 1ES 1312 – 423) are announced at this conference for the first time.

H.E.S.S. observation campaigns on AGNs have been largely based in the past on the criterion proposed in [3], where, briefly, a source is considered a good VHE candidate if it exhibits already high levels of both X-ray and radio emissions. More recently, a new complementary observation strategy is in place since the advent of the *Fermi*/LAT telescope, in which AGNs are targeted if the extrapolation of the GeV spectra (e.g. as given in [4]) to higher energies – taking into account the *EBL*<sup>2</sup> absorption as a function of redshift – indicate that they may have a detectable counterpart in the VHE domain. The spectra of distant blazars are modified by absorption of the VHE  $\gamma$ -rays on the EBL, with an effect which depends on the distance to the source and the EBL level assumed. Correspondingly, for a source at a known distance, if the intrinsic spectrum is assumed (e.g. by extrapolation from lower energies), then a limit can be placed on the EBL level, by evaluating the absorption required to produce the measured spectrum.

The two observation strategies above led to the recent discovery of several new AGNs of the BL Lacertae<sup>3</sup> (BL Lac or blazar) type. The three blazars 1ES 0414 + 009, SHBL J001355.9 – 185406 and 1RXS J101015.9 – 311909 were targeted for observations following [3], while the *Fermi*/LAT catalogue criterion motivated the observation of PKS 0447 – 439 and AP Lib. Moreover, low-redshift X-ray blazars were also proposed to be good candidates for VHE astronomy by [5], and hence some such were also included in the list of possible interesting targets. 1ES 1312 – 423 is one such AGN, whose location is about 2° from the position of the radio-galaxy Centaurus A, a source which has been extensively observed by H.E.S.S. and discovered in VHE  $\gamma$ -rays.

Table 1 summarizes the results presented at this conference in this and the companion proceedings (see references in the table). The main characteristics of the AGNs presented (position, redshift, flux level, mean observing angle, number of standard deviations of the detection, observing strategy) are given, together with the corresponding good quality livetime, which represents

<sup>1</sup>“Crab Units”, i.e., compared to a hypothetical source with the Crab nebula intensity and spectrum at the zenith angle of observation.

<sup>2</sup>Extra-Galactic Background Light, resulting from the combined emission of stars and galaxies from the earliest times of their formation to the present.

<sup>3</sup>BL Lac objects are generally characterized by relativistic jets beamed towards the observer, which are thought to originate the large and rapid variability seen in all energy ranges. Additionally, these objects show high polarization and lack of emission lines.

Source name	RA	Dec	$z$	LT	$\phi_0$	$\theta_{zen}$	$N_\sigma$	Strat.
1ES 0414 + 009 [8]	64.22	1.08	0.287	74	0.5%	26°	7.8	[3]
SHBL J001355.9 – 185406	3.48	-18.90	0.095	38	~ 1%	13°	~ 5	[3]
PKS 0447 – 439 [18]	72.35	-43.84	[0.176, 0.5]	14	4.5%	23°	14	[4]
AP Lib [20]	229.42	-24.37	0.049	11	2%	13°	7	[4]
1RXS J101015.9 – 311909	152.57	-31.32	0.14	33	~ 2.5%	13°	7.2	[3]
1ES 1312 – 423	198.76	-42.61	0.105	168*	0.4%	24°	6.8	[5]

**Table 1:** The six new AGNs detected by H.E.S.S. during the past year. The columns present the source name and corresponding references, position in right ascension and declination in degrees, the redshift  $z$ , observation livetime in hours, flux in C.U., mean observing angle in degrees, significance in number of standard deviations, and finally the references used to guide the observing strategies. The sources detailed in other proceedings at this conference, have this reference in bold besides their names. (\*) For 1ES 1312 – 423 this is the total livetime, but correcting for the camera acceptance this reduces to about 65 hours.

the amount of good quality data after weather selection criteria and corrected for the instrument dead-time.

## 2. 1ES 0414 + 009: one of the most distant VHE blazars with a known redshift

1ES 0414 + 009 is one of the distant sources having a known redshift of about  $\sim 0.29$ , which has been detected by H.E.S.S. with a significance of about  $7.8 \sigma$  after a four-year observing campaign, leading to a total good livetime of about 74 hours (see [8] at this conference). The detection of this faint source (0.5% C.U.) occurred at the same time the *Fermi*/LAT found its GeV emission by analyzing the 21 months dataset; this led to a *Astronomer's Telegram* [7] in which the discovery of the GeV-TeV emissions was announced simultaneously. This AGN is a high-frequency-peaked BL Lac (HBL), where the high-energy part of the spectral energy distribution (SED) shows a peak of the emission above a few TeV. Such a feature is difficult to explain with a standard one-zone SSC scenario, therefore, this source belongs to the class of the hard TeV BL Lac objects, which are challenging for modelling.

## 3. Discovery of SHBL J001355.9 – 185406: first H.E.S.S., then *Fermi*/LAT

The newly-discovered SHBL J001355.9 – 185406, also belonging to the HBL category, is much closer, with a redshift of 0.095. The source is contained among the sources of the RASS/BSC<sup>4</sup> of soft (0.1 – 2 keV) X-ray sources (see [9]), where its flux was found to be  $1.01 \times 10^{-11} \text{ erg/cm}^2/\text{s}$  and is in the NVSS catalogue<sup>5</sup> of radio sources at 1.4 GHz (see [10]) which gives its flux density at 29.5 mJy. The source was selected according to the criterion in [3], but also from the list of 150 HBL sources in the SHBL<sup>6</sup> catalogue (see [11]), where, briefly, interesting VHE targets show an extremely high ratio of X-ray to radio fluxes. The source was not present in the first year

<sup>4</sup>ROSAT All Sky Survey Bright Source catalogue (18811 sources)

<sup>5</sup>NRAO (National Radio Astronomy Observatory) VLA (Very Large Array) Sky Survey ( $1.8 \times 10^6$  sources)

<sup>6</sup>Sedentary High-frequency BL Lacertae

*Fermi*/LAT catalogue, indicating that its flux in the GeV range was below the 1-year sensitivity. H.E.S.S. discovered the VHE emission from this BL Lac object [12] using the two advanced analysis methods mentioned in Sec. 1, with a statistical significance of about  $5\sigma$  above 300 GeV in 38 hours of good quality observations carried out between July 2008 and August 2010, see Fig. 1a for the excess map. The light curve of the source is found to be compatible with a constant flux at the level of  $\sim 1\%$  C.U. The source was monitored in optical wavelengths over the same period by ATOM<sup>7</sup>, operated by the H.E.S.S. collaboration and located next to the H.E.S.S. site. Additionally, *Swift*/XRT [13] observations in the 0.2 – 10 keV energy range were triggered by H.E.S.S. in September 2010. No significant variability in either optical or X-ray bands down to a timescale of a few days has been found. Subsequent to the H.E.S.S. discovery, the *Fermi*/LAT Collaboration announced the detection of a source positionally consistent with the BL Lac with a significance of  $7\sigma$ , see [14]. The *Fermi*/LAT preliminary analysis indicated a faint hard-spectrum source with a 2-year averaged flux above 100 MeV of  $(0.9 \pm 0.7) \times 10^9$  ph/cm<sup>2</sup>/s and a photon index of  $1.5 \pm 0.2$ , considering statistical errors only.

#### 4. PKS 0447 – 439: trying to constrain the redshift

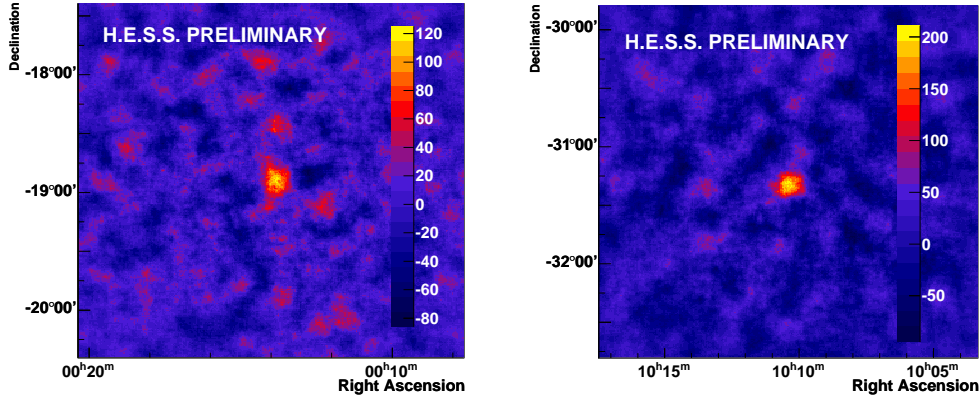
PKS 0447 – 439 is one of the brightest hard-spectrum blazars in the *Fermi*/LAT catalogue. H.E.S.S. observed this source for a total livetime of about 14 hours, announcing the discovery of the VHE  $\gamma$ -ray emission in [15] with a significance of  $14\sigma$ . The redshift of this source is not well known; a value of 0.205 was initially proposed by [16], whereas a more recent study [17] provides only a lower limit of 0.176. The study detailed in [18] at this conference reverses the procedure for the evaluation of the EBL level discussed in Sec. 1. It supposes the EBL to be now known with some certitude and explores the range of acceptable redshifts for which the extrapolation of the spectrum from the *Fermi*/LAT range does not overproduce the predicted spectrum in the H.E.S.S. range, within measurement errors. In this way, an upper limit in redshift of 0.5 was derived at the 95% confidence level.

#### 5. AP Librae: first LBL of the southern hemisphere

AP Librae (AP Lib) is the closest of the new blazars presented here, at a redshift of 0.049, and was targeted for H.E.S.S. observations thanks to the *Fermi*/LAT bright source catalogue. This AGN has been discovered by H.E.S.S. after 11 hours of livetime with a significance of  $7\sigma$  and announced in [19]. The SED (see [20], at this conference) of this source shows that AP Lib is a low-frequency peaked BL Lac (LBL) and presents an extremely broad high-energy component which extends from X-ray to VHE, showing that, for this source, synchrotron X-ray brightness is not required to produce VHE  $\gamma$ -rays and that an external Compton component may be responsible for detected VHE emission. AP Lib is the third LBL detected at VHE and the first one discovered in the southern hemisphere.

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<sup>7</sup>Automatic Telescope for Optical Monitoring



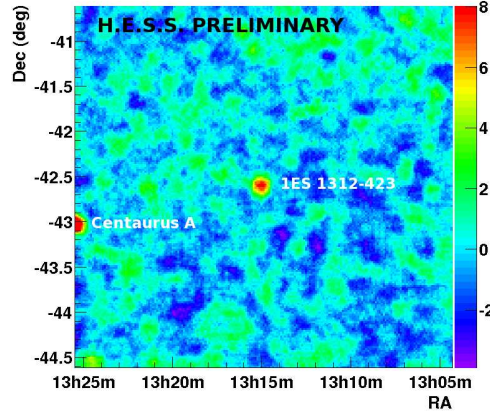
**Figure 1:** *Left panel.* Excess map of the region including the blazar SHBL J001355.9 – 185406. *Right panel.* Excess map of the region including the blazar 1RXS J101015.9 – 311909.

## 6. Discovery of VHE $\gamma$ -rays from the BL Lac object 1RXS J101015.9 – 311909

1RXS J101015.9 – 311909 is a blazar at a redshift of 0.14. The source is a HBL contained in the RASS/BSC catalogue of soft X-ray sources, where its flux is given as  $2.9 \times 10^{-11}$  erg/cm<sup>2</sup>/s and is in the NVSS catalogue of radio sources at 1.4 GHz, where its flux density is 74.3 mJy. This AGN has been shown to be a good candidate for VHE Cherenkov astronomy also for its extremely high X-ray to radio flux ratio, pointed out in the SHBL catalogue, and was not present in the first year *Fermi*/LAT catalogue ([4]). H.E.S.S. observed this AGN in a dedicated campaign between 2007 and 2010 at a mean observing angle of 13°, leading to a total good livetime of 33 hours. The analysis of this AGN was carried out with the two independent enhanced analysis procedures mentioned in Sec. 1, which give consistent results. VHE emission from the BL Lac object 1RXS J101015.9 – 311909 has thus been discovered by H.E.S.S. with an excess of 233  $\gamma$ -ray events, at a significance level of 7.2  $\sigma$ , and is presented at this conference for the first time. The VHE  $\gamma$ -ray excess sky map is shown in Fig. 1b. The flux of the source is about 2.5% C.U., and spectral studies are ongoing.

## 7. Discovery of 1ES 1312 – 423: in the same FoV of Centaurus A

1ES 1312 – 423 is a blazar at a redshift of 0.105 present in the Einstein slew survey sample [21], in the RASS/BSC, and in the *BeppoSAX* spectral survey of BL Lacs [22]. The source was proposed as a good VHE  $\gamma$ -ray candidate by [5], where it was suggested through a simple SSC model that low-redshift X-ray BL Lac objects should have a VHE counterpart. The source was not present in the *Fermi*/LAT first year catalogue. 1ES 1312 – 423 lies at the edge of the FoV of H.E.S.S. for observations centred around the radio-galaxy Centaurus A. H.E.S.S. carried out a deep observation of Centaurus A leading to its discovery in the VHE domain in early 2009 ([6]), reporting a flux level of 0.8% in C.U. For this reason, the data set available for the entire FoV is large, and has been useful to perform a dedicated analysis on this blazar, despite the lower collection efficiency at about 2° distance from the observing position. The source has been analyzed with the



**Figure 2:** Significance map of 1ES 1312 – 423. The source on the left-hand side is the radio-galaxy Centaurus A.

two above-mentioned enhanced analysis methods leading to the discovery of its VHE emission with a  $6.8 \sigma$  significance in 168 hours of good livetime taken between 2004 and 2010. The total corrected livetime, taking into account that the observations were carried out at large offset with respect to the source position, is of about 65 hours. Preliminary studies of the light curve show no detectable variability, similarly to observations in other wavelengths, which were not variable either.

## 8. Conclusions

H.E.S.S. is now in the process of refurbishing the four mirror surfaces and building a new very-large telescope, in preparation for the operation of its second phase, which will begin in 2012. The new telescope will permit to lower the threshold to about 30 GeV in the single-telescope mode, opening a complementary observational window to high-energy phenomena. As negligible  $\gamma$ -ray absorption is expected in the 30 – 100 GeV energy range, therefore more distant objects will become visible, enriching the extra-galactic source catalogue and permitting to put stronger constraints on the EBL. By enriching the array with the addition of a fifth telescope at the centre, the experiment will be about a factor of two more sensitive with respect to the present configuration in multi-telescope mode. In the meantime, H.E.S.S. has succeeded in enhancing its sensitivity uniquely by the development and successful application of new, more powerful analysis methods. Thanks to the enhanced sensitivity provided by these new methods, sources which were not seen with the standard analyses, became detectable. At this conference, six newly-detected AGNs have been presented, the discovery of two of which (1RXS J101015.9 – 311909 and 1ES 1312 – 423) has been shown for the first time. While the detections of PKS 0447 – 439 and AP Lib were motivated by the *Fermi*/LAT catalogue of bright sources, the discovery of SHBL J001355.9 – 185406 was first achieved at VHE by H.E.S.S., and subsequently by *Fermi*/LAT, integrating over a larger dataset. The SEDs of 1ES 0414 + 009 and AP Lib have peculiar features which are difficult to explain with standard one-zone SSC scenarios, giving intriguing inputs for the modelling of LBLs and HBLs. With the detection of 1ES 0414 + 009 and 1ES 1312 – 423, two blazars having flux levels of 0.5%

and 0.4% C.U., H.E.S.S. enriches the catalogue of the weakest-ever sources detected in VHE  $\gamma$ -rays. These recent discoveries demonstrate that the field of extragalactic VHE  $\gamma$ -ray astronomy is very active and will become more so with the advent of the second phase of H.E.S.S.: HESS-II.

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